ACCURACY ASSESSMENTS OF POINT CLOUD 3D REGISTRATION METHOD FOR HIGH ACCURACY CRANIOFACIAL MAPPING

Zulkepli Majid, Halim Setan and Albert K. Chong
Photogrammetry and Laser Scanning Research Group
Faculty of Geoinformation Sciences & Engineering
Universiti Teknologi Malaysia
zulkeplimajid@utm.my

ABSTRACT

Three dimensional (3D) laser scanning technology has found to be an excellent method for modeling and measuring 3D objects. The 3D point clouds of an object can be acquired within less than one second and stored digitally for pre-processing task. Complex mapping of 3D object such as human faces required at least two scanning images to cover the complete facial area (from right ear to left ear, and from hair line to bottom part of the chin) with optimum 3D modeling accuracy. For complete 3D model generation, the scanning images are needed to be registered and merged together. Existing registration method used corresponding features between the two scanned images as registration primitive and finally 3D transformation algorithm was applied to register the images. This paper describes the use of photogrammetric targets, as registration primitive to register two scanning images of human face. The so called "paper targets" were setup on the special design photogrammetric control frame where the human face was placed at the middle of the frame during scanning process. The photogrammetric control frame was calibrated using close-range convergent photogrammetry with coded targets and high precision scale bars to determine the precise 3D coordinate of such targets. The targets were also included in the scanning images and represented as point clouds. Via laser scanning images, the centroid of the targets was precisely measured and the 3D transformation algorithm was successfully applied to transform the scanning point clouds from laser scanning coordinate system to photogrammetric coordinate system. The output of the registered point clouds was displayed and processed in reverse engineering RapidForm 2004 software. The accuracy of the method was evaluated using shell-shell deviation analysis method where the average deviation of the two scanning images was calculated. The results show that the accuracy of the 3D registration accuracy using photogrammetric targets was measured to be 0.129mm to 0.285mm. The reliability of the 3D registration accuracy using photogrammetric targets method was also evaluated and the standard deviation of the method is 0.10mm to 0.50mm.

Keywords: 3D registration, laser scanning, photogrammetric targets, point clouds, craniofacial mapping

1.0   INTRODUCTION

Close-range photogrammetry can be defined as the art, science and technology of obtaining reliable information from photographic images taken at less than 300 m object distance (Majid et

al, 2005a). The advantages of close-range photogrammetric method are the subject being measured does not have to actually be touched. The measurement carried out by the close-range photogrammetric method requires the used of high accuracy retro-reflective targets with measured 3D coordinates. Three dimensional (3D) laser scanning provides fast and high accuracy method for 3D surface modeling of an object. The laser scanner offers three types of scanning resolution, based on triangulation, phase-based and time-of-flight. The triangulation laser scanner provides the most accurate 3D surface model with scanning distance between 0.6 to 2.5 meters (Chong et al, 2004; Majid et al, 2004; Setan et al, 2004; Setan et al, 2005). Laser scanning method requires more than one scan data for the complete modeling of 3D object. Therefore, more scan data are needed from each part of the 3D object. The registration method is used to register the scan dataset for the complete modeling of the object. The 3D registration process using iterative closest point method (Besl and Mckay, 2002) required the user to digitized at least three corresponding points that appeared on the 3D surfaces in triangle form. As shown in **Figure 1**, it is difficult to select the corresponding features as the features were not accurately captured and modeled by the laser scanners. The left and right model failed to register together and the error of the registration process was shown in **Figure 2**. This paper describes the details on the integration of close-range photogrammetry and 3D laser scanning for high accuracy 3D modeling of craniofacial spatial data (soft tissue) by improving the accuracy of the registration process of 3D point clouds data. The needs for precise registration of 3D laser scanner data using photogrammetric targets is essential to solve the problem when the lacked of corresponding features on two laser scanner dataset are happened.
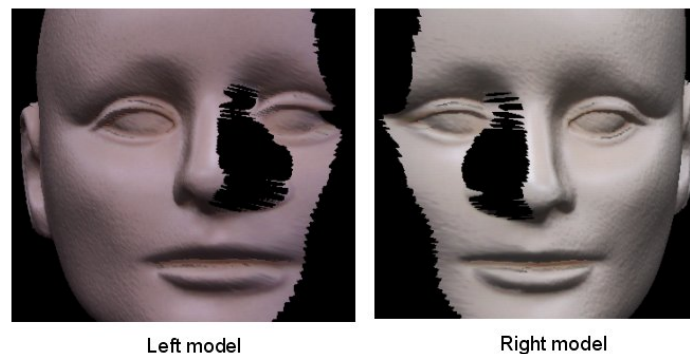

Left model   Right model

Figure 1: The lacked of corresponding features on 3D laser scanner surface model
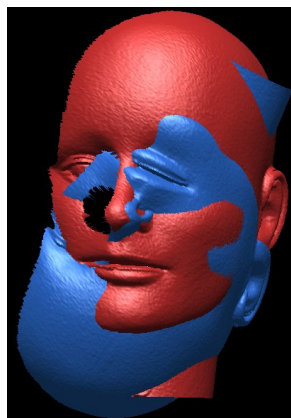

Figure 2: Error in 3D registration process – effect from the lacked of corresponding features

Therefore, the new method applying close-range photogrammetric targets as a tool to register the laser scanner point clouds datasets was developed to overcome the registration problem. The details of the new 3D registration method were described in the following sub-chapters.

2.0 SETUP OF THE TEST

The test was carried out using the Imetric System (Imetric, Switzerland) consisted of hardware and software. The process started with the calibration of the "photo-laser control frame" which was specially designed for craniofacial mapping task. The "photo-laser control frame" consisted of close-range photogrammetric targets (as shown in **Figure 3**). The control frame was designed to have different in depth value by using 30mm diameter cylindrical rod attached on the plate (Majid et al, 2005b). Four coded targets were stick-on the plate for automatic calibration process. Two scale bars with coded and paper targets were used to supply scaling on the measurements. Fifty convergent images (normal and roll views) were captured using Minolta A200, eight million pixels digital cameras within 1 meter object distances.
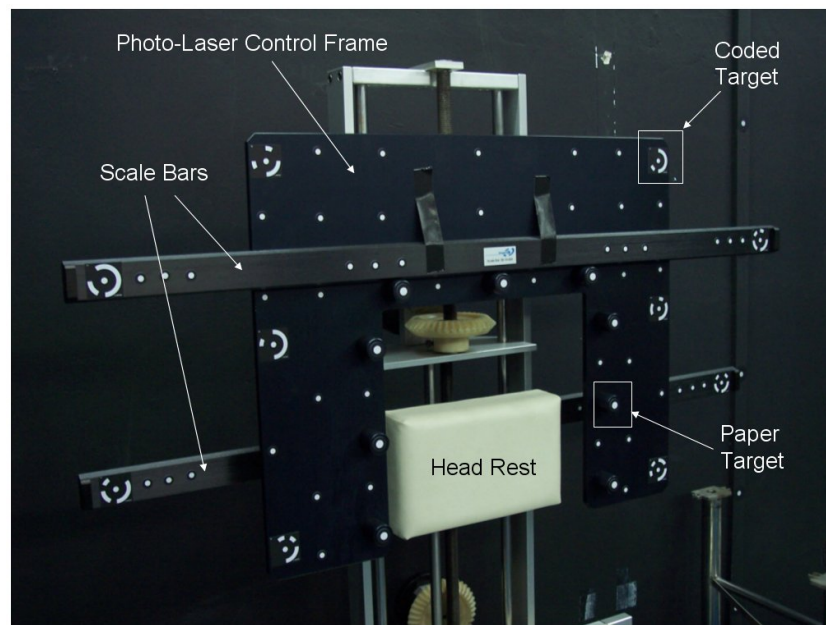

Figure 3: The "Photo-Laser Control Frame" – setup during the calibration process

The photogrammetric image processing (using IMetric Software System) started with relative orientation (RO) measurements to predict the preliminary 3D coordinates of the targets. By using coded targets, the RO process allowed automatic measurement of the targets in each image. The bundle adjustment method was finally performed to refine the 3D coordinates of the targets. The overall accuracy of measured 3D coordinates was 0.018mm, 0.025mm and 0.028mm for X, Y and Z, respectively. The targets were then used as a control for the 3D registration process of the point clouds datasets. **Table 1** shows the X, Y and Z coordinates of the targets.

Table 1: X, Y and Z coordinates of the targets

ID	X (mm)	Y (mm)	Z (mm)
701	141.3276	34.9785	19.3886
702	141.3956	125.8587	-0.5542
703	141.3602	215.448	19.3843
704	200.1451	273.2141	-0.6870
705	290.2756	274.6969	19.3047
706	380.5301	273.3969	-0.3822
707	441.6218	214.2141	19.7036
708	440.0886	125.1733	-0.0980
709	441.5747	35.5981	19.7020

The second step of the case study involved with the scanning process of the test objects using Minolta VIVID 910 three-dimensional laser scanners. The case study involved with two test objects; (a) the mannequins (as in **Figure 4**) and (b) real-life human faces (as in **Figure 5**). Both test objects were placed at the middle of the photo-laser control frame.
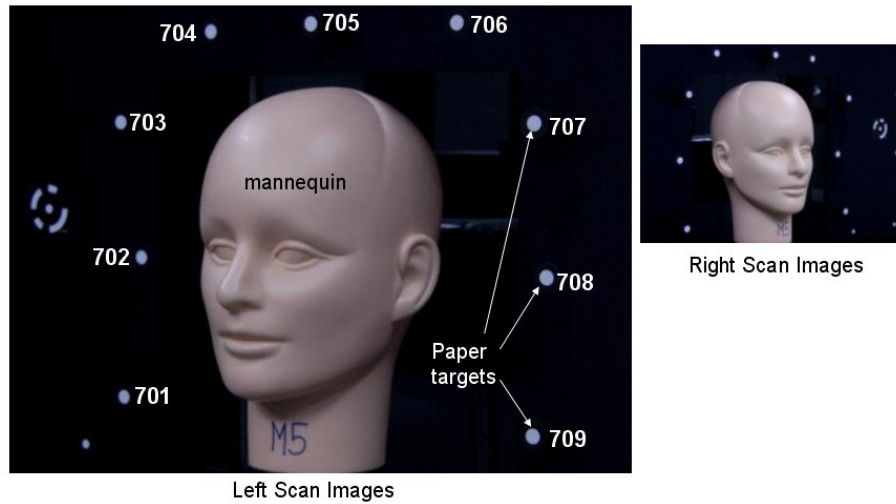
Figure 4: Mannequin as test object for accuracy testing of the new method
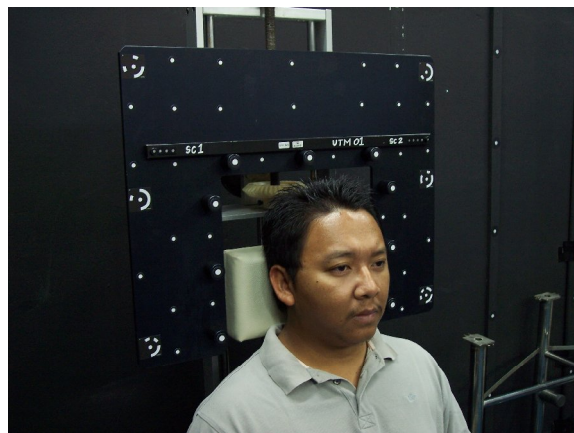
Figure 5: Position of the real-life human head during data capture

3.0   PRE-PROCESSING OF LASER SCANNING DATASETS

The data input for the registration process is the 3D coordinate of the targets (determined by photogrammetric method) and the laser scanner point clouds datasets (in cdm format). The cdm format consists of two laser scanner data, the 3D point clouds and the color images taken by the built-in CCD camera. For the purpose of measuring the targets in laser scanner data, the color images were used and the sub pixel target measurement method was applied. The centroid of the photogrammetric targets in the images is similar to the centroid on such targets in point clouds datasets. **Figure 6** shows the pre-processing tasks involved in the development of final craniofacial 3D model using the new 3D registration method.
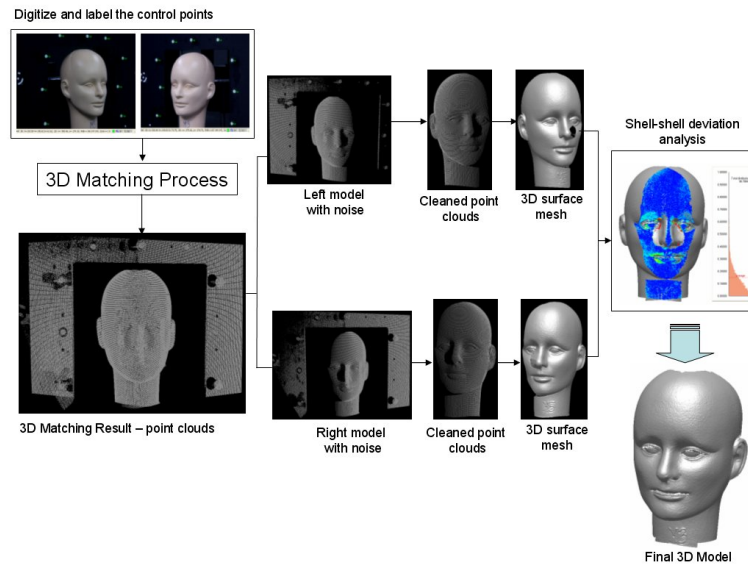

Figure 6: Pre-processing tasks for the development of final 3D model of craniofacial

4.0   RESULTS

The reliability test of the new method was evaluated using three different mannequins with different sizes to represent the three types of ages. Each mannequin was scanned at five different periods (range in 5 minutes) with fixed scanning configuration (high resolution with 300,000 point clouds per scanning, scanning angle at 90 degree and scanning distance at 850mm). For each scanning datasets, nine photogrammetric targets were used and manually digitized and labeled. The reliability of the new method was determined by the matching accuracy, average distances accuracy between the point clouds and the standard deviation of the deviations. The results of the reliability test were shown in Table 2.

The similar reliability test was carried out on the real life human faces (as shown in **Figure 7**). The test on both mannequins and real life human faces shows that the accuracy of the shell-shell deviation accuracy between the left and right scan images is increased between 0.129mm to 0.285mm compared to 0.30mm to 0.50mm by using the corresponding features method (as reported in Boehnen and Flynn, 2005; Kusnoto and Evans, 2002; Kau et al, 2004; Kovacs et al, 2006).

**Table 2: Reliability test results of the new 3D registration method –
Test on the mannequins**

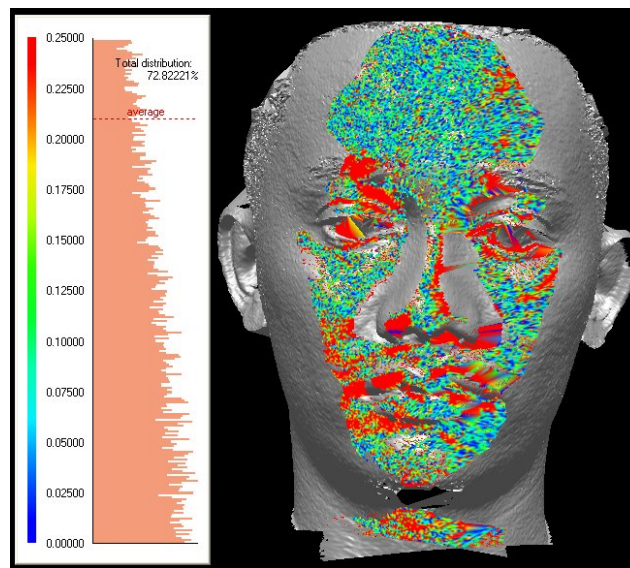| Number of Testing	Shell-shell deviation accuracy (mm)		
	Test on Mannequin 1	Test on Mannequin 2	Test on Mannequin 3
Test 1	0.285	0.261	0.129
Test 2	0.251	0.209	0.137
Test 3	0.271	0.221	0.241
Test 4	0.267	0.274	0.236
Test 5	0.272	0.234	0.200

Figure 7: Shell-shell deviation analysis of real life human face 3D model

5.0   CONCLUSION

The advantages of the new method are the method increased the accuracy of the registration of 3D laser scanner datasets. The average shell-shell deviation accuracy is recorded to be less than 0.30mm. Apart from the accuracy aspect, the percentages of the coverage of the scanning area was increased without having a problem with the lacked of corresponding scanning area, since the registration process is based on photogrammetric targets which was attached on the photo-laser control frame and where the modeling from left ear to right ear and from the hair line to the bottom part of the chin can easily be captured.

The disadvantages of the new method are the registered laser scanner datasets is in 3D point clouds form. The texture data, triangle mesh data and 3D surface mesh data, which was captured during the scanning task, was terminated from the datasets. The final output is a set of x, y and z coordinates of the point clouds written in ASCII format. The problems required the user to re-generate the triangulation mesh and 3D surface mesh of the laser scanner datasets based on raw 3D point clouds. The texture mapping of the data required extra images from

other sources such as digital images captured from digital camera or video camera that setup along with the laser system.

REFERENCES

Besl, P.J. and Mckay, N.D., 1992. A method for registration of 3-D shapes. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 14(2): 239–256.

Boehnen, C. and Flynn, P., 2005. Accuracy of 3D Scanning Technologies in a Face Scanning Scenario. Proceedings of the Fifth International Conference on 3-D Digital Imaging and Modeling, pp. 310-317.

Chong, A.K., Majid, Z., Ahmad, A., Setan, H. and Samsudin, A.R., 2004. The Use of National Craniofacial Database. *The New Zealand Surveyor Journal*, No. 294, June 2004.

Kau, C.H., Zhurov, A., Scheer, R., Bouwman, S. and Richmond, S., 2004. The Feasibility of Measuring Three-Dimensional Facial Morphology in Children. *Orthodontics Craniofacial Research*, 7, 2004: 198-204.

Kusnoto, B. and Evans, C., A., 2002. Reliability of a 3D Surface Laser Scanner for Orthodontic Applications. *American Journal of Orthodontics and Dentofacial Orthopedics*, Vol. 100, No. 4, October 2002.

Kovacs, L., Zimmermann, A., Brockmann, G., Baurecht, H., Schwenzer-Zimmerer, K., Papadopulos, N., A., Papadopulos, M., A., Sader, R., Biemer, E. and Zeilhofer, H.,F., 2006. Accuracy and Precision of the Three-Dimensional Assessment of the Facial Surface Using a 3-D Laser Scanner. *IEEE Transactions on Medical Imaging*, Vol. 25, No. 6, June 2006.

Majid, Z., Setan, H. and Chong, A., 2004. Modeling Human Faces with Non-Contact Three Dimensional Digitizer – Preliminary Results. *Geoinformation Science Journal*, Vol. 4, No. 1, pp. 82-94.

Majid, Z., Chong, A. K., Ahmad, A., Setan, H. and Samsudin, A., R., 2005a. Photogrammetry and 3D Laser Scanning as Spatial Data Capture Methods for a National Craniofacial Database. *The Photogrammetric Record*, 20(109): 48-68.

Majid, Z., Chong, A., Setan, H. and Ahmad, A., 2005b. Craniofacial Stereo Mapping: Improving Accuracy with Natural Points. *The New Zealand Surveyor Journal*, No. 295, December 2005.

Setan, H., Majid, Z. and Suwardi, D., 2004. The Development of Image Capturing System and Information System for Craniofacial Reconstruction. Proceedings of 3rd FIG Regional Conference, Jakarta, Indonesia, October 3-7, 2004.

Setan, H., Ibrahim, M. S. and Majid, Z., 2005. Precise Measurement and 3D Modeling for Medical and Industrial Applications: Verification Tests. Proceedings of FIG Working Week 2005 and GSDI-8, Cairo, Egypt, April 16-21, 2005.

AUTHORS

Dr. Zulkepli Majid is a senior lecturer at the Faculty of Geoinformation Science & Engineering,Universiti Teknologi Malaysia. Currently, he is the head of Photogrammetry and Laser Scanning Research Group. He holds BSc.(Land Surveying) degree, M.Sc (Photogrammetry) degree and a PhD (Medical Photogrammetry) degree from Universiti Teknologi Malaysia, Malaysia. His research interests lie in the areas of Photogrammetry and Laser Scanning for various applications. His current research projects are the application of photogrammetry in forensic and assets data capture using terrestrial laser scanner.

Dr. Halim Setan is a professor at the Faculty of Geoinformation Science and Engineering, Universiti Teknologi Malaysia. He holds B.Sc. (Hons.) in Surveying and Mapping Sciences from North East London Polytechnic (England), M.Sc. in Geodetic Science from Ohio State University (USA) and Ph.D from City University, London (England). His current research interests focus on precise 3D measurement, deformation monitoring, least squares estimation and 3D modeling.

Dr. Albert K. Chong is a senior lecturer at the Faculty of Engineering and Surveying, University of Southern Queensland. He holds B.Sc in Photogrammetry from California State University, Fresno, M.Sc. (Civil Engineering) from the University of Washington and a PhD (Civil

Engineering) from The university of Washington. His research interests lie in the areas of close-range photogrammetry and close-range laser scanning. He has authored over 137 articles in both international and national refereed journals, conference proceedings, and workshop in field of engineering, surveying, photogrammetry, laser scanning and GPS.